Update

2021.01.16 HU Qingyong

Outline

- A survey of scenarios of mmWave sensing

Activity Recognition

	mHomeGes	mmGait	mmASL	RF-Wash
Publication	IMWUT'20	AAAI'20	IMWUT'20	Sensys'20
Scenario	Activity Recognition	Gait Recognition	ASL Recognition	Track hand hygiene
Medium	76-81 GHz FMCW	60GHz / 77GHz FMCW	60 GHz	60 GHz sinusoidal wave
Equipment	TI-IWR1443 76-81 GHz mmWave radar-on-a-chip sensor with 3 Tx and 4 Rx antennas	IWR1443: 77GHz 4GHz FMCW IWR6843: 60.25GHz 3.75GHz FMCW	NI multi-FPGA + V-band RF frontend and phased antenna array; 12 for Tx and 12 for Rx	TI mmWave IWR1443 sensor operates in 60GHz to collect RF measurements at 8Hz.
Core Technique	Concentrated position-doppler profile + NN + HMM + Voting	mmGaitNet	Doppler Spectrogram + multi-task learning	CNN+BiLSTM to trained on unsegmented naturally-performed hand hygiene technique.
Performance	10 multi-joint arm gestures with an average accuracy of 97.96% in 164ms average latency.	Dataset of 95 volunteers; 90% for single person and 88% for 5 co-existing persons.	50 ASL signs 87% average accuracy	Gesture error rate of < 8%
Limitation	1. FoV 60° and range 4.8m 2. Need large data collection 3. Cannot recognize new users	1. Directly learning without considering multipath and environment	1. Orientation 2. Not COTS 3. Degraded with untrained users 4. Degraded with the presence of interferer in the same beam	1. Require user to be stationary 2. Unseen subjects

Activity Recognition

	[Avishek, et.al]	RadHAR	[Thomas et,al.]
Publication	mmNets'18	mmNets'19	mmNets'20
Scenario	Gesture Recognition	Activity Recognition	Activity Recognition
Medium	57 - 64GHz	76GHz – 81GHz	57-64 GHz
Equipment	Single –chip omni Radar RIC60a radar 57-64GHz 80°x25° beamwidth	TI IWR1443BOOST radar 76GHz – 81GHz	Infineon's BGT60TR13C 57-64GHz FMCW
Core Technique	Unsupervised self-organized map and supervised learning vector quantization	Accumulate point clouds over a sliding window then voxelized and fed into a classifier	A novel Euclidean distance-based softmax that overcomes the angular dependency and allows a classification solely on Euclidean distances
Performance	SOM 75% LVQ 60% Two radars can increase 10% accuracy.	5 activities: 90.47%	7 activities: around 90%
Limitation	1. Power profile easily influenced 2. Need two radars	1. Single person 2. Influenced by spatial and temporal	1. Does not consider angular information

Security

	WaveSpy	E-Eye	VocalPrint
Publication	Oakland'20	Sensys'18	Sensys'20
Scenario	Screen Attack	Hidden Electronics Recognition	User Authentication
Medium	24-24.45 GHz	24-24.45 GHz	77-81 GHz FMCW
Equipment	4 x 4 antenna arrays self-designed as E-Eye	4 x 4 antenna arrays self-designed	TI AWR 1642 mmWave probe 77 GHz- 81 GHz
Core Technique	Liquid crystal nonlinear effects + Wavelet-based analysis + SVM + WaveSpyNet	Nonlinear response effect from electronic circuits. + Wavelet-based nonlinear response analysis and feature extraction	Detect throat vibrations + extract biometric features
Performance	99% screen content type recognition and a success rate of 87.77% in Top-3 sensitive information retrieval.	46 commodity electronic devices, accuracy more than 99%	41 participants with different interrogation distances, orientations and body motions, 96% accuracy.
Limitation	1. Multiple displays 2. User orientation	1. Metal Obstruction 2. Multiple E-devices	1. Body motion near-throat can influence the performance 2. Distance 2m

Fine Displacement (Vibration) Sensing

	WaveEar	mmVib	RF-SCG	Osprey	VocalPrint
Publication	Mobisys'19	Mobicom'20	Mobicom'20	Mobisys'20	Sensys'20
Scenario	Speech Sensing	Vibration measurement	Seismocardiography	Sense tire wear	User Authentication
Medium	24 GHz	77-81 GHz	77-81 GHz	77-81 GHz	77-81 GHz FMCW
Equipment	Designed mmWave probe + 16 antennas Tx Rx	TI IWR1642 77-81GHz FMCW radar	IWR1443BOOST board operates at 77 GHz with a bandwidth of 4 GHz.	77 GHz mmWave AWR1642.	TI AWR 1642 mmWave probe 77 GHz- 81 GHz
Core Technique	Spectrum + residual NN + phase reconstruction	Multi-signal consolidation	4D Cardiac Beamformer + CNN + U-Net	Inverse Synthetic Aperture RADAR algorithm	Detect throat vibrations + extract biometric features
Performance	Localize the position of the speaker among multiple people	1. Median amplitude error is 3.4um for the 100um-amplitude vibration.	1. Time five key cardiovascular events with a median error between 0.26%-1.29%.	1. Median absolute tire wear error of 0.68 mm ;	41 participants with different interrogation distances, orientations and body motions, 96% accuracy.
Limitation	1. 2m 2. Environment dependent	1. Cannot deal with dynamic interference from surrounding objects 2. Only 1D vibration	1. Influenced by environment 2. User must stay almost static.	1. Operating at tire speeds up to 5.45 kmph. 2. Need to know the geometry of tires.	1. Body motion near-throat can influence the performance 2. Distance 2m

Fine Displacement (Vibration) Sensing

	mSense	mmVital	mmSense
Publication	IMWUT'20	Mobihoc'16	mmNets'19
Scenario	Material Detection	Vital Sign	Detection and Identification
Medium	60 GHz	60 GHz	60 GHz
Equipment	Qualcomm 60GHz 802.11ad chipsets; Tx and Rx contains 32 antennas as a 6x6 phased array	Keysight EXG N5172B produces a 10MHz baseband signal and input to the Vubiq transmitter	Keysight EXG N5172B produces 10 MHz signal and up-converted to 60 GHz.
Core Technique	Material Reflection Feature + CIR	RSS + Mechanically rotate	RSS Traces + Fingerprints generation + LSTM + Body Surface Boundary + Vital signs
Performance	93% in five common types of materials: aluminum, ceramic, plastic, wood and water.	Breath rate: 0.43 Bpm Heart rate: 2.15 bpm	5 person 88%
Limitation	1. FoV: incident angle is limited to 10 degree. 2. Cannot detect similar materials	1. Not COTS 2. Need to mechanically rotate Tx and Rx 3. RSS easily influenced	1. RSS easily influenced 2. Not COTS

Tag for mmWave

	FerroTag	ThermoWave
Publication	Sensys'19	Mobicom'20
Scenario	Tagging infrastructure	Passive temperature monitoring
Medium	24 GHz	24 GHz with 250MHz bandwidth
Equipment	24GHz with 450MHz FMCW	ThermoTag: a cholesteryl material; 24GHz FMCW radar.
Core Technique	FerroRF effects: magnetic nanoparticles within the ferrofluidic ink reply to probing mmWave with classifiable features.	Thermal scattering effect
Performance	99% in lab, 97% in real-world	1. ±1.0°F in the range of 30°F to 120°F in a controlled setup. Real-world: ±3.0°F.
Limitation	1. Influcenced by sensing angle	1. Influenced by environment 2. Range of 2m 3. Occluded by metallic

Tracking and Localization

	mTrack	mWaveLoc	milliMap	milliEgo	POLAR
Publication	Mobicom'15	Sensys'18	Mobisys'20	Sensys'20	Infocom'20
Scenario	Fine-grained Tracking	3D device-based Localization	Indoor mapping	Egomotion estimation	Passive Object Localization
Medium	60 GHz	60 GHz	77-81 GHz	77-79 GHz	60 GHz
Equipment	WARP + Vubiq 60GHz RF front-end, two Rx and 1 Tx	4 x 8 element phased-array used by 802.11ad devices	TI AWR1443 board 77GHz-81GHz fmcw; Velodyne VLP-16 Lidar	TI AWR1843 board Xsens Mti-1 IMU Intel D435i Depth Camera Velodyne HDL-32E lidar	MikroTik wAP 60G routers uses a Qualcomm Atheros QCA6335 60GHz chipset, antenna array 6 x 6.
Core Technique	phase + RSS	CIR + select a constant number of beams that amplify the LOS path most + correlates beam amplitudes with beam patterns + FTM	A generative learning approach that combine cross-modal supervision from mmWave radar and lidar.	1. Two-stage cross-modal attention layer to promote complementary sensor behaviors.	CIR and Sector Level Sweep to estimate AoD and ToF
Performance	90% error below 8mm	Median distance error is 4cm, median angular error is 11.5°. Median estimation error is 75cm. 3D median estimation error is 17cm.	A map reconstruction error less than 0.2m and classify key semantics with accuracy of ~90% operating through smoke.	1.3% error.	4 APs localize a moving robot with a metallic surface 6.5cm mean accuracy
Limitation	1. Multi receiver 2. Only 50cm x 50cm 3. Only tracks micro object	1. 80% error is much larger than median error. 2. Need scan all beams	1. Influenced by different buildings and obscurants. 2. Only a single agent to build a map. 3. Need to retrain on different buildings	1. Unknown how milliEgo will generalize to other indoor spaces 2. Drifts with distance increasement.	1. Limited by device's beam patterns 2. Low and irregular reflectivity of clothing did not allow for sufficiently strong reflections.

Imaging

	Millipoint	Pointillism	[Haitao Zheng et,al.]	HawkEye	Ulysses
Publication	Ubicomp'20	Sensys'20	Mobicom'15	CVPR'20	Mobisys'17
Scenario	3D point cloud generation	3D bounding box estimation with multi-radars	imaging	imaging	imaging
Medium	mmWave	77 GHz + 2240MHz bandwidth	60 GHz	60 GHz FMCW + SAR platform	60GHz 802.11.ad
Equipment	TI dual-chip FMCW(4GHz) Radar sensor with 6 Tx and 8 Rx antennas.	IWR1443BOOST FMCW	Wilocity 60 GHz 2 x 8 rectangular antenna array 802.11ad standard	ADF4159 PLL 60GHz with 1.5GHz bandwidth + SAR FUYU FSL40 liner sliders	8 x 16 rectangular phased array
Core Technique	SAR imaging Design an automatic multi-focusing to overcome the effect of specular reflection.	Use multi-radars to produce Cross Potential Point Clouds; RP-net to estimate 3D bounding box.	RSS Series Analysis	cGAN and data synthesizer	Beamforming RSS, emulate monostatic synthetic aperture radar without using phase but using angular and signal strength information
Performance	1. Can image specular objects with even 60° orientation deviation.	1. Median error of less than 37cm in localizing the center of an object bounding box and a median error of less than 25cm in estimating the dimensions of the bounding box.	Orientation error within 1° location error within 10cm	9.3% car surface missed	8cm error in width and 1° error in orientation
Limitation	Quasistatic requirement of SAR	Radar's angular resolution is 15°. Need multi-radar	1. Unable to detect small objects 2. Easily influenced by environment because of RSS	1. Tend to overfit a single kind of images	1. 2D movements 2. Cannot handle device rotation erros 3. Mutlipath reflection

Multi-Person

	mmTrack	ViMo	MU-ID	mmGait	mmVital	mmSense
ublication	Infocom'20	IoTJ'20	Infocom'20	AAAI'20	Mobihoc'16	mmNets'19
cenario	Multiperson localizing	Respiration / Heart rate	Gait Recognition	Gait Recognition	Respiration / Heart rate	Detection and Identification
Iedium	60 GHz	60 GHz	77-81 GHz	60GHz / 77GHz FMCW	60 GHz	60 GHz
quipment	Qualcomm 60GHz 802.11ad chipsets; Tx and Rx contains 32 antennas as a 6x6 phased array	Qualcomm 60GHz 802.11ad chipsets; Tx and Rx contains 32 antennas as a 6x6 phased array	TI AWR1642BOOST	IWR1443: 77GHz 4GHz FMCW IWR6843: 60.25GHz 3.75GHz FMCW	Keysight EXG N5172B produces a 10MHz baseband signal and input to the Vubiq transmitter	Keysight EXG N5172B produces 10 MHz sign and up-converted to 6 GHz.
ore echnique	MVDR beamformer + adaptive detection + K-Means	CIR + dynamic programming in spectrogram	Lower-limb movements + Feature Separation + Segmentation	mmGaitNet	RSS + Mechanically rotate	RSS Traces + Fingerprints generatio + LSTM + Body Surface Boundary + Vital signs
erformance	Median accuracy 9.9cm, 90% 22.5cm	Median error: Respiration rate 0.19 BPM Heart rate: 0.92 BPM 3 users	97% single-person and over 92% for up to 4 people	Dataset of 95 volunteers; 90% for single person and 88% for 5 co-existing persons.	Breath rate: 0.43 Bpm Heart rate: 2.15 bpm	5 person 88%
mitation	1. Cannot predict user number more than 3	1. FOV 100° 2. Distance 2.5m	1. Influenced by environment 2. 120° FOV	1. Directly learning without considering multipath and environment	1. Not COTS 2. Need to mechanically rotate Tx and Rx 3. RSS easily influenced	1. RSS easily influenced 2. Not COTS